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Conserving Biodiversity in Vietnam: Applying Biogeography to Conservation Research

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Vietnam has recently become the focus of renewed research efforts, whose results have highlighted the country's endemic biota and intrinsic species richness. The roots of this diversity are multiple and include Southeast Asia's complex geological and climatic past, Vietnam's wide range of latitudes (23° to 8°30′N) spanning a subtropical-tropical transition zone, and the country's relatively hilly and mountainous topography. The region has attracted the interest of biogeographers since the mid-ninetecnth century and a variety of biogeographic units and hypothesized distribution patterns has been derived from studies of Southeast Asia's diversity. Multitaxon surveys were undertaken in three little-studied and currently unprotected areas to aid in conservation efforts by adding to species diversity and distribution records and by examining the underlying patterns of biodiversity distribution. Results include new taxa, generic revisions, new country records, and significant range extensions. Data are consistent with some but not all of the proposed biogeographic patterns; both geographic scale and taxonomic group appeared to influence the results.

Situated along the eastern margin of the Indochinese Peninsula, Vietnam covers roughly 329,500 km^2 and is bordered to the north by China, to the west by Lao People's Democratic Republic (Laos) and Cambodia, and to the east by the South China Sea (known in Vietnam as the East Sea). Vietnam lies at a crossroad of biological diversity. A north-south orientation of more than 1650 km incorporates biotic regimes from the temperate Himalayas and the Chinese Palearctic zone in the northwest and northeast, the northern Indian zone to the west, and the tropical Malaysian zone to the south.

In the early to mid-1990s, Vietnam achieved global recognition for its unique and endemic species, generated in particular by a rush of large mammal species "discoveries" and rediscoveries emanating from the Truong Son Mountain Range (also known as the Annamite Range or Annamite Cordillera). These findings encompass six mammal species,[1] including the 85–100-kilogram saola (*Pseudoryx nghetinhensis*), an entirely new genus in the oxen family and the largest land-dwelling mammal described since 1937 (Amato et al. 1999; Pham Mong Giao et al. 1998; Pine 1994; Schaller and Vrba 1996; Surridge et al. 1999; Vu Van Dung et al. 1993). In addition to larger mammals, an impressive array of other organisms have recently been uncovered in this and other areas of Vietnam between 1992 and 2004, including over 200 taxa of vascular plants (Regalado in litt.

[1] Large-antlered muntjac (*Muntiacus vuquangensis*), Annamite muntjac (*Muntiacus truongsonensis*), Roosevelt's muntjac (*Muntiacus rooseveltorum*), saola (*Pseudoryx nghetinhensis*), Heude's pig (*Sus bucculentus*), and Annamite striped rabbit (*Nesolagus timminsi*).

2003), three birds,[2] three turtles, four snakes, 14 lizards, 31 frogs, and, since 2000 alone, 29 fish and over 500 invertebrates (Bain et al. 2003; Eames et al. 1999a; Eames et al. 1999b; Eames and Eames 2001; Zoological Record 2002).

These discoveries are coming to light now for several reasons. First, there has been a general increase in scientific research as Vietnam emerges from decades of political strife. Second, scientists — both Vietnamese and foreign — have increasingly, if sporadically, been given greater access to sensitive military buffer zones along the border with contiguous countries, where much of Vietnam's remaining naturally forested areas lie.

A third and related factor contributing to the large number of new species is the country's intrinsically high rate of species richness and endemism. Using data from the World Atlas of Biodiversity (Groombridge and Jenkins 2002) on plant, bird and mammal species richness per unit area, Vietnam ranks 25th in the world in terms of species richness. Examples of this diversity can be found across taxonomic groups. Vietnam's vascular plants have remarkable levels of species richness and endemism for such a small country, particularly in light of the taxonomic work that still needs to be done. Botanists estimate there to be around 13,000 species of vascular plants in Vietnam, 8,000 of which have been identified to date. This represents a little over 2% of the world's currently described species (Lecointre and Le Guyader 2001; Rundel 2000). Within the family Cycadaceae, Vietnam harbors 24 species of cycad, representing over 12% of the world's cycad species and subspecies (Donaldson 2003; Nguyen Tien Hiep and Phan Ke Loc 1999). Another example of elevated species richness can be found in the primate community. Twenty-seven primate taxa (19 species and eight subspecies) in the families Loridae, Cercopithecidae, and Hylobatidae live in Vietnam, seven of which are endemic to the country (Brandon-Jones et al. 2004).

Patterns of endemism in Vietnam are not well researched, but to date elevated floral endemism has been recorded in the northwest's Hoang Lien Son Range, the limestone regions of Cao Bang Province, Pu Mat and Pu Luong Nature Reserves in the northern Truong Son range, the Da Lat Plateau and adjacent montane areas of the southern Truong Son range, and the forested dunes and semi-arid slopes along the south-central coast near Nha Trang, Cam Ranh and Phan Ranh (Rundel 2000; Fig. 1). In some parts of Vietnam, such as the Fan Xi Pan massif in the northwest, the rates of vascular plant endemism rise to 40% (Nguyen Nghia Thin and Harder 1996). Faunal endemism in Vietnam is the highest in Indochina (Vietnam, Laos, Camboidia) (MacKinnon 1997). This may be due in part to a sampling artifact: Vietnam is currently better known than the other countries.

Historical and Current Conditions

Vietnam's wealth of biological diversity stems from its complex geology and climate and its geographic location. The dynamic nature of these conditions both now and in the past has strongly influenced the biological richness of the country. Geologically, Southeast Asia is one of the world's most complex regions, at the interface of three converging continental plates: Eurasia, Indo-Australia and the Philippine Sea plates (Hall 1998). Vietnam itself comprises a collage of continental fragments that broke off sequentially from the "supercontinent" Gondwanaland 400–200 million years ago and migrated north to fuse at higher latitudes (Metcalfe 2001). Due to this complex geological history, Vietnam's mountains are composites of marine sediments, rocks of metamorphic and volcanic origin, and ancient uplifted basement formations (Fontaine and Workman 1978; Hutchinson 1989).

[2] Black-crowned barwing (*Actinodura sondangorum*), golden-winged laughingthrush (*Garrulax ngoclinhensis*), and chestnut-eared laughingthrush (*Garrulax konkakinhensis*).

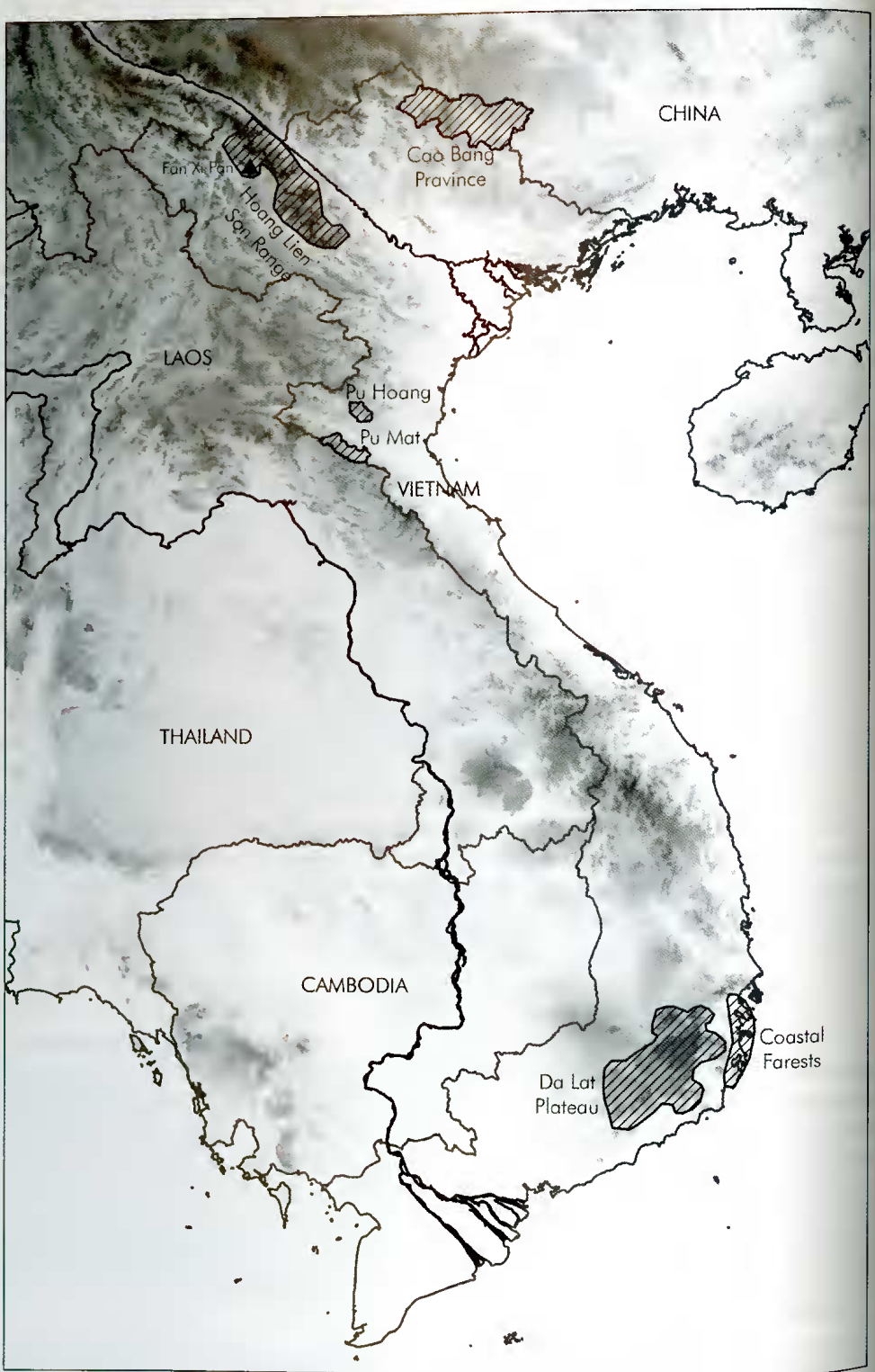


FIGURE 1. Areas of Vietnam (shaded) with high recorded floral endemism. All boundaries are approximations.

A more recent geologic event, the India-Eurasia collision about 50 million years ago, had profound impacts on Southeast Asia's evolutionary history, introducing new groups of organisms, creating dispersal barriers and modifying the climate (Hall 1998; Morley 2000). The rising of the Himalayas over the last 20 million years effectively cut off the exchange of species between the Palearctic and Indo-Malayan realms. This barrier, reinforced by increased climatic cooling after the Miocene, isolated Indo-Malaya and created conditions for species divergence (Jablonski 1993; Macey, et al. 1998). Additionally, the rise of the Tibetan Plateau as a result of this impact shifted rainfall, winds and other climatic patterns in East and Southeast Asia to become more monsoonal and strongly seasonal, increasing habitat diversity (An 2000; Clift et al. 2002).

Long-term oscillations in climatic conditions seem to have greatly affected distribution and dispersal of species in Southeast Asia. Starting in the Tertiary, global cooling events led to falling sea levels and an increase in the amount of exposed land area (Bennett 1997; Hewitt 2000). Unlike large land masses, such as South America, where sea levels 70 or 100 m below present levels had little effect, the smaller land areas and island archipelagos of Southeast Asia lie on the shallow Sunda Continental Shelf and their connectivity is strongly affected by sea level fluctuations (Heaney 1991). At 75 m below present level, the submerged shelf formed a bridge that likely served as a corridor between mainland Southeast Asia and the Sunda Islands, including Sumatra, Java, and Borneo (Voris 2000; Fig. 2).

Increased land area, coupled with a reduced South China Sea, led to decreasing moisture content of monsoon winds, resulting in cooler, drier conditions (An 2000; Zhou et al. 1996). Montane forest vegetation descended to lower levels, supplanting lowland evergreen rainforest forms, and grassland biomes replaced rainforests in more seasonal areas. During interglacial periods, the climate became warmer, wetter and less seasonal, and evergreen rainforest habitats expanded to retake higher elevations and latitudes; sea levels also rose to cover continental shelves, cutting off the land bridges (Kershaw et al. 2001; Morley 2000). These changes allowed populations in Southeast Asia to go through cycles of divergence and re-colonization, contributing to the high levels of species richness and endemism that now characterize the realm (MacKinnon 1997).

Contemporary seasonal climate fluctuations also shape Vietnam's biodiversity. Seasonality increases as one moves from south to north, away from Southeast Asia's perhumid core centered on Borneo, Sumatra, and the tip of Peninsular Malaysia. The dominant climatic feature is the monsoon circulation pattern, which directly influences the seasonality of rainfall. In the winter, strong north-east monsoon winds are produced as air flows from cold high pressure areas in Asia along the eastern edge of the Tibetan Plateau towards a hot low pressure zone over Australia, bringing dry winds to some of Vietnam. In the summer, southwestern monsoon winds flow from high-pressure areas over Australia and the Indian Ocean towards the interior of China, releasing water picked up over the seas as summer rains (An 2000).

These dynamic circulation patterns interact with regional land and ocean configurations, exposing Vietnam to a wide variety of rainfall regimes. Vietnam's hilly and mountainous topography influences the distribution of species and biotic communities by mediating temperature and humidity both locally at different altitudes and at a landscape level via rain shadow effects. Vietnam's elongated shape covers 14 degrees of latitude north to south, encompassing a wide range of climates and topographic relief overlying a variety of rocks and soils. The combination of local microclimates and the soil and substrate complexity has, in turn, shaped vegetative communities (Rundel 2000). Vietnam's major topographic feature, the Truong Son Range, runs roughly north to south along the Vietnam-Laos border and into south-central Vietnam. It forms an important barrier between the moist uplands of Vietnam and the drier monsoon forests of Laos and Cambodia and traverses the transition zone between the subtropical northern and the tropical southern climates.

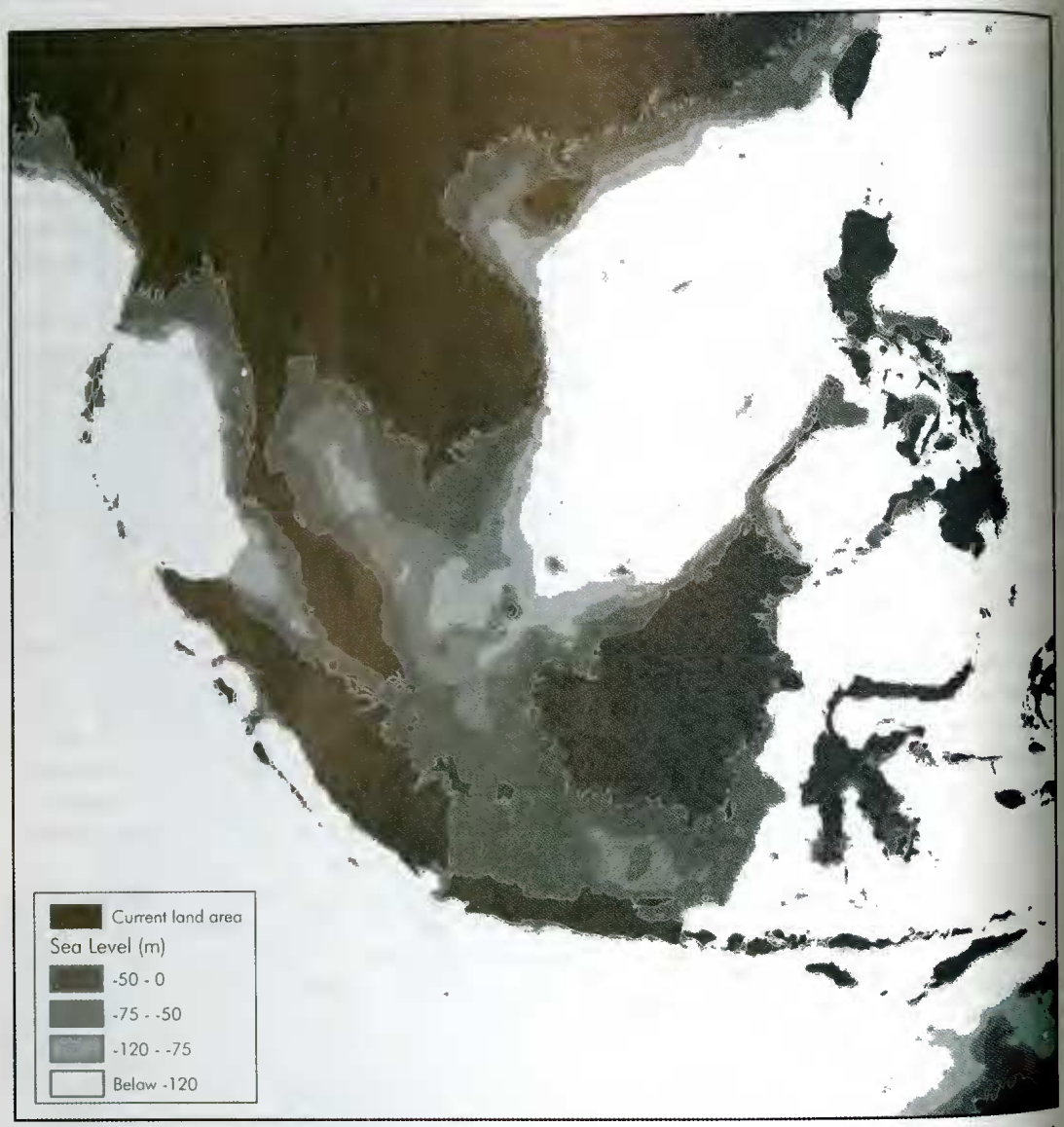


FIGURE 2. Map of Southeast Asia illustrating depth contours at 50, 75 and 120 m below current sea level. After Voris (2000). Reproduced with permission of the Field Museum of Natural History.

Broad biogeographic patterns reflecting these varied conditions have been identified and are frequently referenced when describing Vietnam's biodiversity (e.g., Eames et al. 2001; Hill 2000; Nguyen Nghia Thin and Harder 1996). Vidal (1960), Udvardy (1975), and MacKinnon (1997) have each defined biogeographic units within the Indochinese subdivision of the Indo-Malayan biogeographical realm. The most recent and detailed of these works places Vietnam at the convergence of four bio-units: Indochina (northwest and north-central Vietnam), South China (the northeast), Annamese Mountains (two regions in the central and southern Truong Son), and Coastal Indochina (the majority of central and southern Vietnam) (Fig. 3). Evolutionary and ecological evidence for these units is still being gathered. What evidence is there to date supporting these divisions and the

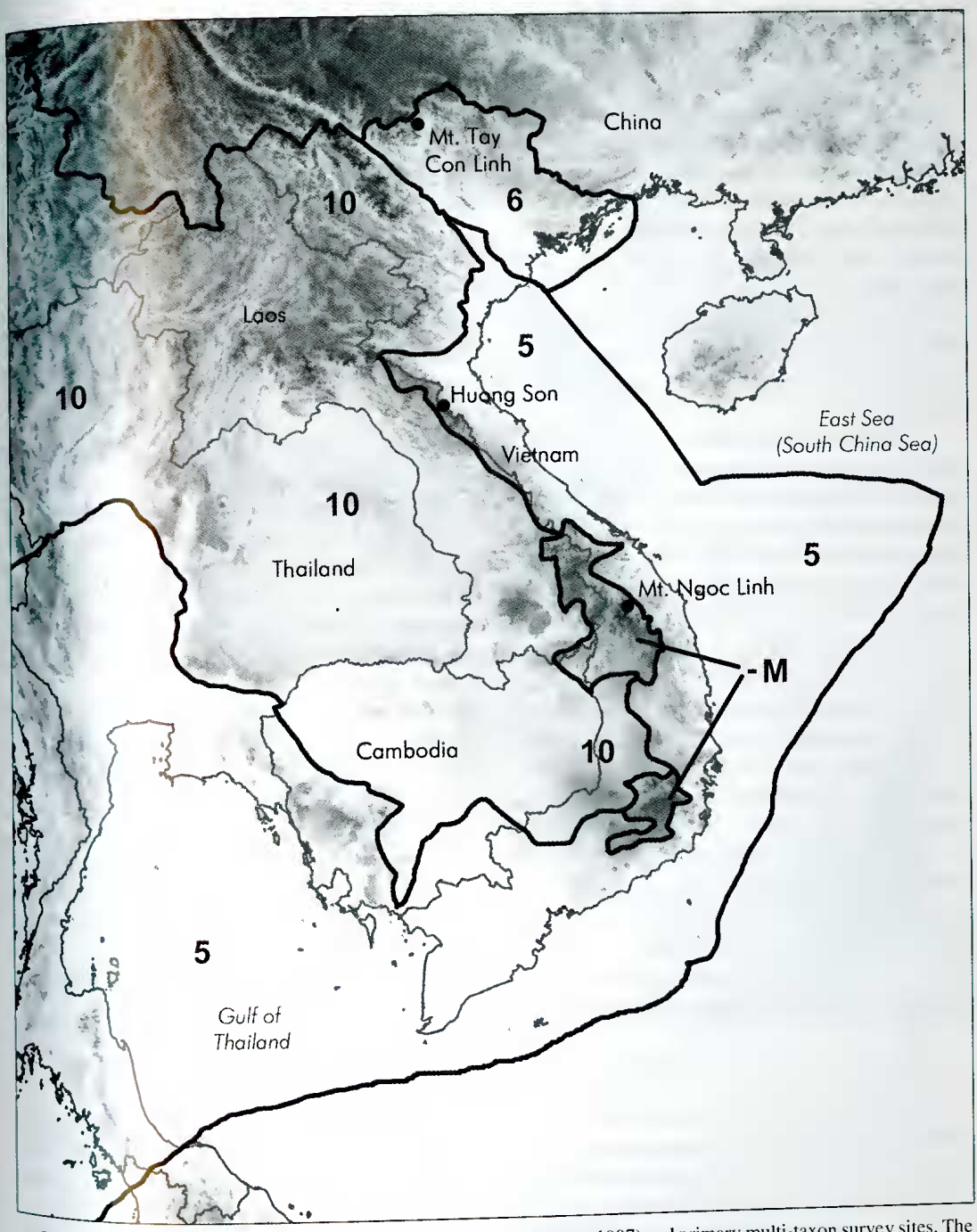


FIGURE 3. Map illustrating Vietnam's major bio-units (after MacKinnon 1997) and primary multi-taxon survey sites. The biogeographic units are: Coastal Indochina (Unit 5), Southern China (Unit 6), Indochina (Unit 10) and the Annamese Mountains (Unit -M). Study site localities were: Mt. Tay Con Linh, Cao Bo Commune, Vi Xuyen District, Ha Giang Province (22°46′N, 104°52′E; surveyed 2000 and 2001); Rao An, Huong Son District, Ha Tinh Province (18°22′N, 105°13′E; surveyed 1998 and 1999); and Mt. Ngoc Linh, Tra My District, Quang Nam Province (15°11′N, 108°02′E; surveyed 1999).

specific roles of the region's geological and climatic history in shaping its biodiversity?

One supporting example comes from recent research in Vietnam and Laos. The ranges of the recently described Annamite striped rabbit (*Nesolagus timminsi*) and the newly rediscovered Heude's pig (*Sus bucculentus*) are both currently restricted to small areas of the northern Truong Son range bordering Laos and Vietnam. Their likely closest relatives, the Sumatran striped rabbit (*Nesolagus netscheri*) and the Javan warty pig (*Sus verrucosus*), respectively, live approximately 2500 km to the south, on the islands for which they are named (Groves et al. 1997; Surridge et al. 1999; Fig. 4). Genetic data suggest that the two rabbit species have been diverging for approximately eight million years (Surridge, et al. 1999). A similar pattern is seen in the distribution of Lovi's reed snake (*Calamaria lovii*) whose four subspecies are distributed allopatrically, one each in Vietnam's central Truong Son, Peninsular Malaysia, Java and Borneo (Darevsky and Orlov 1992). These may represent relict populations of formerly widespread ancestral species once connected by the emergent Sunda Shelf and isolated when seas rose and fell and forests expanded and contracted.

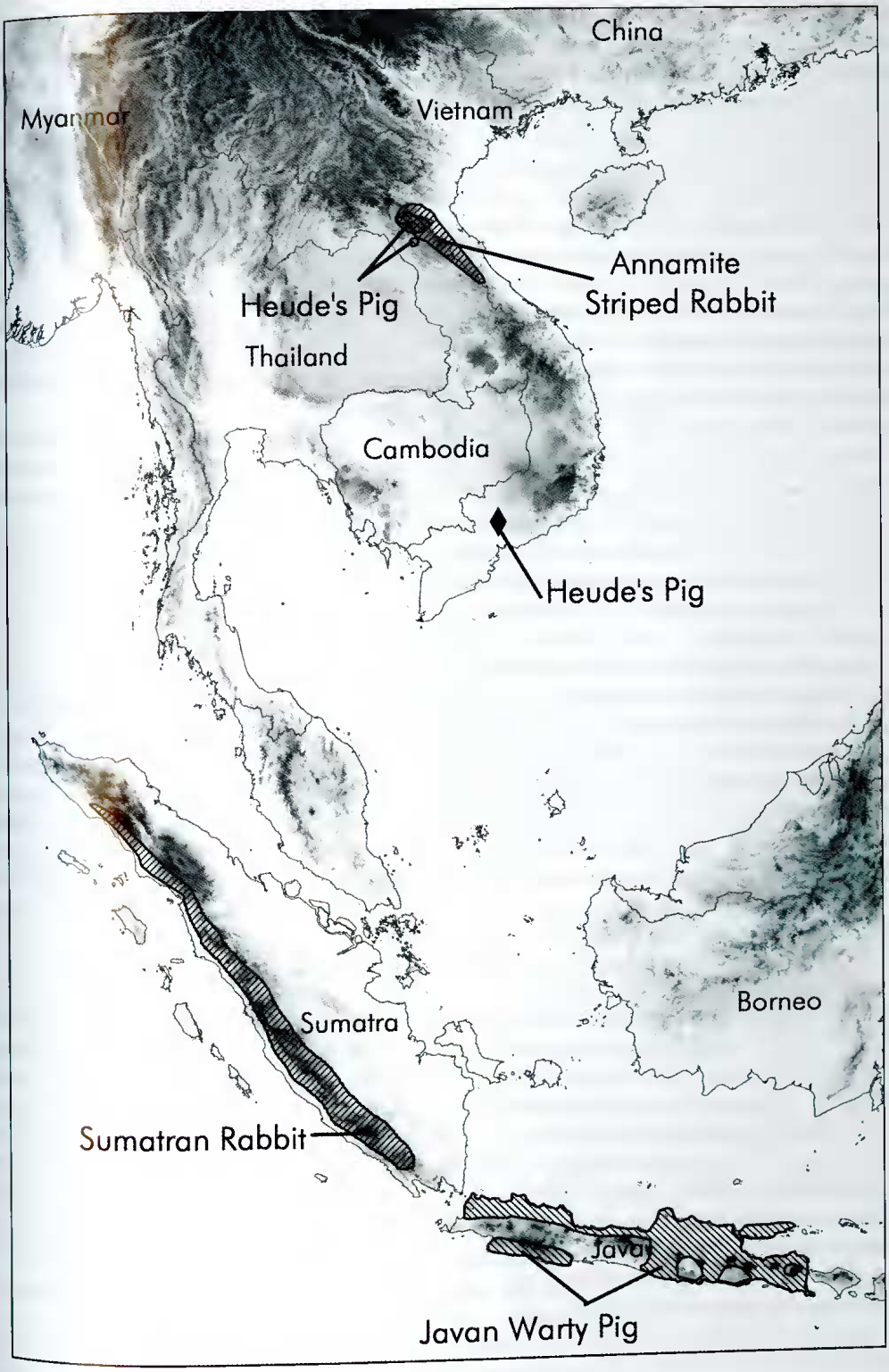
Within Indochina there is also a tentative suggestion that ancient climate fluctuations have influenced Vietnam's species diversity. Analyses of overlapping species distribution patterns in mainland Southeast Asia for a number of different taxonomic groups have led scientists to suggest that the Truong Son range served as a refugium for forest-dwelling species during cooler, drier times (Brandon-Jones 1996; Groves and Schaller 2000; Rabinowitz 1997; Surridge et al. 1999; Timmins and Trinh Viet Cuong 2001; but see Gathorne-Hardy, et al. 2002 for an alternative list of refugia). The refugium theory was first put forth to explain patterns of species richness in South America (Haffer 1969). In its initial formulation, the theory infers that observed diversity patterns stem from cycles of rainforest habitat contraction (forming refugia) and expansion that repeatedly isolate populations and lead to speciation events. Some scientists have challenged and revised this theory, suggesting instead that long-term climatic stability in refugia leads to high species diversity by facilitating both the evolution of recent 'neo-'endemics and the persistence of older "paleo"-endemics (Colinvaux et al. 2000; Fjeldså et al. 1999; Fjeldså and Lovett 1997). The two theories are not mutually exclusive.

The Kon Tum and Da Lat Plateaus of the Truong Son Range are both recognized as areas of high bird endemism, and the range is the home to three large mammal species considered relatively "primitive" members of their respective lineages (saola, Heude's pig, and the Annamite striped rabbit) (Flux 1990; Groves et al. 1997; Hassanin and Douzery 1999; Stattersfield et al. 1998; Tordoff et al. 2000). Elucidation of potential refugia in mainland Southeast Asia lies in future phylogenetic analyses of potentially informative taxa.

Current Conservation Efforts

Clearly, extensive research remains to be done on Vietnam's biodiversity and biogeography. This research has both theoretical and practical implications. Vietnam faces considerable challenges in attempting to conserve its rich and endemic biodiversity. Species distributions remain poorly known (as evidenced by the high number of rediscoveries), population data are lacking for almost all organisms, and ecosystem-level interactions are practically unknown. Vietnam harbors

FIGURE 4 (right). Map illustrating the historical ranges of the Sumatran rabbit (*Nesolagus netscheri*) and the Javan warty pig (*Sus verrucosus*) and the current known distributions of the Annamite striped rabbit (*Nesolagus timminsi*) and Heude's pig (*Sus bucculentus*). The two specimens on which the initial description of Heude's pig was based originated in southern Vietnam; it is unclear if these were collection localities or points of purchase. All ranges are approximations. Data from Dang N. Can, et al. (2001); Flux (1990); Groves and Schaller (2000); and Oliver (1993).


China
Myanmar
Vietnam
Annamite
Striped Rabbit
Heude's Pig
Thailand
Cambodia
Heude's Pig
Borneo
Sumatra
Sumatran Rabbit
Javan Warty Pig

five of the world's 25 most endangered primates, four of which are endemic to the country and one, the grey-shanked douc (*Pygathrix nemaeus cinerea*), only described in 1997 (Conservation International 2002; Nadler 1997). Vietnam's rich biodiversity currently exists in a precarious and fragile state, and there are realistic fears that some of it will be lost before it is identified (Vo Quy and Le Thac Can 1994). Our understanding of Vietnam's diversity is burgeoning just as its species and ecosystems are facing increasing pressure brought on by the country's high human population (80 million people) and far-reaching political and economic changes.

In 1986, the government of the People's Republic of Vietnam initiated *Doi Moi*, heralding individual responsibility in agriculture and more encouragement of commerce (Werner and Bélanger 2002). The market economy has brought new levels of prosperity to Vietnam and made possible expanded rates of consumption. It has also created severe disparities of income. Vietnam now stands at a crossroads as it adjusts to an opening international market economy. The country's accelerating pace of development raises serious concerns for the minority populations and for the long-term prospects for the country's unique natural resources.

Current threats to Vietnam's biodiversity include direct exploitation through logging and hunting (both for subsistence and for national and international markets) and habitat degredation (Compton and Le Hai Quang 1998; DeKoninck 1996; Nguyen Nghia Bien 2001; Pham Binh Quyen and Truong Quang Hoc 2000; Poffenberger and Nguyen Huy Phon 1998). Habitat loss and degradation result from conversion of natural lands to agriculture (including the expansion of cash crops: Vietnam is now the world's second largest coffee exporter; Stein 2002), hydropower projects, urbanization and pollution (BirdLife International in Indochina 2003; Dudgeon 2000; Vo Tri Chung et al. 1998).

The Vietnamese government has a relatively long history of trying to address the problem of environmental degradation. In 1962, Ho Chi Minh established one of Vietnam's first protected areas, Cuc Phuong National Park. By 1990, the number of forest reserves had grown to 90, covering 1.3 million hectares (about 4% of the country). In 1995, The Ministry of Agriculture and Rural Development (MARD), the government arm charged with protected area development and administration, set a finite target of two million hectares for protection of forested areas (Birdlife International, 2001). The government simultaneously initiated a review of current and proposed protected areas aimed at removing degraded, non-forest lands from the current network and achieving equal representation of all Vietnam's habitats and associated biodiversity (Wege et al. 1999).

Biogeography and Conservation Research

In an effort to contribute to Vietnam's restructuring of its protected area system, the Center for Biodiversity and Conservation at the American Museum of Natural History (CBC-AMNH) collaborated with a number of other organizations on multi-taxon surveys of currently unprotected forested areas in Vietnam. Collaborators included the Institute of Ecology and Biological Resources (Hanoi) (IEBR), Vietnam National University (Hanoi) (VNNU), the Forest Inventory Protection Institute in the Ministry of Agriculture and Rural Development (Hanoi) (FIPI-MARD), Missouri Botanical Garden (MBG), World Wildlife Fund (WWF), and BirdLife International. Our goals were to survey three areas outside of the current protected area network to determine the diversity of plants and animals found in them, to identify cultural and subsistence uses of the areas for local populations, and to assess the conservation value of these areas in the context of both existing protected areas and additional proposed ones.

Study area selection was guided by a number of criteria. Areas had to be poorly known, forested, relatively undisturbed but still accessible for field work, and representative of biotic communi-

ties inadequately covered by the current protected areas network. We also used a biogeographic framework in combination with previous research to select areas potentially rich in biodiversity and ones where survey results could further elucidate the structure of diversity and its distribution in Vietnam. Our goal was to test two biogeographic hypotheses using survey results from study sites along north-south and east-west gradients: (1) the contributions of different biota (Sino-Himalayan, southern Chinese and Indo-Malayan) to regional diversity across the country, and (2) the existence of an endemic focus along the eastern flank of the Truong Son Range (Baltzer et al. 2001; MacKinnon 1997; Stattersfield et al. 1998; Timmins and Trinh Viet Cuong 2001). We also looked at elevation gradients to examine the relative roles of latitude and altitude in defining communities.

The most northerly site, Mt. Tay Con Linh in Ha Giang Province, lies in the South China bio-unit, east of the Red River and close to the Chinese border (Fig. 3). Habitats include submontane to montane evergreen and mixed deciduous evergreen forests typical of northern Vietnam's granitic mountains with a high diversity of conifers (Birdlife International 2001; Bain and Nguyen Quang Toruong 2004a; Harder, *in litt.* 2001). Vietnam west of the Red River has been better surveyed than the northeast (e.g., Bourret 1936, 1941, 1942; Delacour 1930; Delacour et al. 1928a; Delacour et al. 1928b; Eames and Ericson 1996; Osgood 1932); complementary efforts on the eastern side allow us to examine whether or not the Red River is an important barrier structuring diversity (Geissmann et al. 2000; MacKinnon 1997; Orlov et al. 2001). The most southern site, Mt. Ngoc Linh in Kon Tum Province, is part of the central Truong Son Range, a region known as the Western or Central Highlands, and it lies within the northern Annamese Mountain bio-unit (Fig. 3). Mountain plateaus in this region have elevated rates of endemism and BirdLife International has recently designated the Kon Tum Plateau an Endemic Bird Area (Vietnam's fourth) following the description of three new babbler species from it (Eames and Eames 2001; Eames et al. 1999a; Eames et al. 1999b; MacKinnon 1997; Tordoff et al. 2000). The forest sampled here is composed of low to medium montane broadleaf evergreens. The third site, Huong Son in Ha Tinh Province, lies roughly midway between the other two study areas in the northern Truong Son Range, within the Coastal Indochina bio-unit (Fig. 3). The low mountains in this area, which run along the Vietnam-Laos border, have been the site of some of the recent large mammal descriptions, e.g., saola (Vu Van Dung et al. 1993). The Huong Son study area encompassed lowland to lower montane broadleaf evergreen forests.

Researchers from the AMNH and collaborating institutions surveyed mammals, birds, amphibians, reptiles, freshwater fish, invertebrates and plants. At each of the major study sites, scientists sampled three to five locations along an elevation gradient. Whenever possible, workers on different taxonomic groups directly coordinated their sampling methods at each elevation. Taxon-specific sampling methods were employed with the general project goal of maximizing recorded diversity, including potentially undescribed species and species not yet known from the area. Collected specimens have been deposited at the AMNH, MBG, and IEBR. A detailed summary of study areas, methods, personnel, and results to date is available elsewhere (Hurley 2002).

Data from the 1998-2000 survey collections are still being analyzed, and most results remain preliminary. As with many other recent surveys, we collected previously undescribed species and recorded significant range extensions for both relatively well-known (e.g., Mrs. Gould's sunbird *Aethopyga gouldiae*) and recently described (e.g., an endemic glass snake *Ophisaurus sokolovi*) taxa. Notable descriptions (all in progress except the mammal) include a new shrew (*Chodsigoa caovansunga*), a new babbler (*Jabouilleia* sp.) and a minimum of four new anuran species (Bain and Nguyen Quang Truong2004a, b; Lunde et al. 2003; Sweet and Vogel, in prep.; Vogel et al. 2003). Results from the 1999 amphibian collections at Mt. Ngoc Linh illustrate the potentially high

productivity of continued surveying in Vietnam. Of the 26 species recorded, 10 are restricted-range species, four represent range extensions of more than 200 kilometers for species endemic to Vietnam, two have been described as new and two more are currently being described (Bain and Nguyen Quang Truong 2004b; R. Bain, pers. commun. 2003; Hurley 2002).

Results are consistent with the hypothesis that there may be elevated rates of endemism in the central part of the Truong Son Range. As mentioned above, 10 (40%) of the amphibians collected at Mt. Ngoc Linh are currently known only from a small area, and the new taxa represent possible additional endemics (Bain and Nguyen Quang Truong, in prep.). The new babbler species, collected at the northern site (Mt. Tay Con Linh), necessitates a revision of the endemic Vietnamese genus *Jabouilleia*, types of which are known (currently as subspecies) from along the Truong Son Range (Sweet et al., in prep.). The likely result of these revisions is the elevation of one or more of these subspecies to the species level, adding to recorded endemism in the central Truong Son (Robson 2000). This revision may also contribute to understanding the regional evolutionary processes that have produced differentiation between Vietnam's central and northern avifauna. No additional, clear evidence of faunal endemism was found in the surveys of Huong Son in the northern Truong Son although the presence of three recently described and endemic mammals was recorded (Large-antlered muntjac, *Muntiacus vuquangensis*, saola, and Annamite striped rabbit) (Timmins and Trinh Viet Cuong 2001).

There is preliminary support for the contribution of biota from different biogeographical zones, although this varies with the geographic scale of the analyses. The two major biogeographic units intersecting in Vietnam are the northerly Sino-Himalayan and the southerly Indo-Malayan, with South Chinese influence in the northeast and endemic areas in the Truong Son Mountains (de Laubenfels, 1975; MacKinnon 1997). At a broad scale, collections from the northern (Huong Son) and southern (Mt. Ngoc Linh) Truong Son sites generally include elements of both major faunal groups whereas those from northeastern Vietnam (Mt. Tay Con Linh) show a strong affinity for the fauna of southern China.

At a smaller geographic scale, however, the results are less clear. One factor that disrupts these simple predictions of north-to-south diversity gradients is endemism. The presence of endemic species in the collections from Mt. Ngoc Linh adds a unique component to the fauna, reducing its similarity to the other two sites. For some taxonomic groups (frogs, gibbons) the Red River has been proposed to be a potentially significant geographic barrier, separating divergent eastern and western fauna in northern Vietnam (Geissmann et al. 2000; Orlov et al. 2001). If true, this has strong implications for conservation priorities and protected area designation in the region. Collections from Mt. Tay Con Linh in northeastern Vietnam support this hypothesis for some taxonomic groups but not for others. Insectivora species, collected during the small mammal surveys, include a number of species (e.g., *Scaptonyx fusicaudus, Blarinella griselda*) with stronger affinities to the fauna of southeastern China and Hainan Island than to the rest of Vietnam (Lunde, et al. 2003). However, both bird and amphibian and reptile surveys recorded a large number of range extensions across the Red River to northeastern Vietnam (Bain and Nguyen Quang Truong 2004a; Vogel et al. 2003). These results are not surprising as the newly recorded species fall within expected ranges, and they caution against assuming divergence between regions experiencing different surveying efforts. Our mixed evidence both supporting and refuting this hypothesis suggests that the taxonomic group being considered is an important consideration in the application of biogeographic theory to conservation.

Endemism and species distributions are important components in both biogeographic hypotheses and conservation decision-making. On a cautionary note, care should be taken in attributing full endemic status to new species as well as those known only from intensively surveyed areas. They

may represent "bastard endemics," species which, because of habitat loss or exploitation, now occupy only a subset of a formerly larger geographic range (e.g., the Indochinese Javan rhinoceros *Rhinoceros sondaicus annamiticus*) (Corbet and Hill 1992). Alternatively, they may be more widely distributed but not yet recorded from other areas because of undersurveying, because they were not previously recognized, or for both reasons.

Our experiences incorporating biogeographical information into conservation and biodiversity research have been positive. The surveying efforts were facilitated by our selection of study areas potentially high in species diversity and endemism and ones that might be informative in elucidating Vietnam's underlying patterns of diversity. Results from these surveys and analyses can inform conservation efforts, guiding decisions specifically about the current study areas and more broadly about other locations and communities in Vietnam. They also provide data for testing and refining biogeographical hypotheses, including the geographic and taxonomic scales at which they are applicable. These, in turn, can be used to refine and focus additional research and conservation efforts. An important component to continuing this natural history collections-based work is training and capacity building in Vietnam. Throughout the surveys, AMNH scientists provided equipment and training in standard field data collecting procedures and in the curation of the resulting collections to their counterparts at IEBR and university students. This work has already been productive: IEBR biologists used camera trapping to rediscover the hairy-nosed otter, *Lutra sumatrana*, in Vietnam, a Sundaic species thought to be extinct in Vietnam (Nguyen Xuan Dang, et al. 2000).

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Literature Cited

Amato, G., M.G. Egan, and A. Rabinowitz. 1999. A new species of muntjac, *Muntiacus putaoensis* (Artiodactyla: Cervidae) from northern Myanmar. *Animal Conservation* 2:1–7.

An, Z. 2000. The history and variability of the East Asian paleomonsoon climate. *Quaternary Science Reviews* 19:171–187.

Bain, R.H., and Nguyen Quang Truong. 2004a. Herpetofaunal diversity of Ha Giang province in Northeastern Vietnam with descriptions of two new species. *American Museum Novitates* (3453:1–42.

Bain, R.H., and Nguyen Quang Truong. 2004b. Three new species of narrow-mouthed frogs (Genus *Microhyla*) from Indochina, with comments on *Microhyla annamensis*. *Copeia* 2004:507–524.

Bain, R.H., A. Lathrop, R.W. Murphy, N.L. Orlov, and Ho Thu Cuc. 2003. Cryptic species of a cascade frog from Southeast Asia: taxonomic revisions and descriptions of six new species. *American Museum Novitates* (3417):1–60.

Baltzer, M.C., Nguyen Thi Dao, and R.G. Shore. 2001. *Towards a Vision for Biodiversity Conservation in the Forests of the Lower Mekong Ecoregion Complex*. WWF Indochina, Hanoi, Vietnam. 109 pp.

Bennett, K.D. 1997. *Evolution and Ecology: The Pace of Life*. Cambridge University Press, Cambridge, England, UK. 241 pp.

Birdlife International. 2001. *Sourcebook of Existing and Proposed Protected Areas in Vietnam*, BirdLife International and the Forestry Inventory and Planning Institute, Hanoi, Vietnam. (CD-Rom.)

BirdLife International in Indochina. 2003. Endangered species rediscovered in Yok Don National Park, Dak Lak Province. *The Babbler* 2:12–13.

Bourret, R. 1936. Les Serpents de l'Indochine. 2 vols. Imprimeries Henri Basuyau & Cie., Toulouse, France.
Bourret, R. 1941. Les Tortues de l'Indochine. Memoires de l'Institute Oceanographique de l'Indochine, Hanoi, Vietnam. 235 pp.
Bourret, R. 1942. Les Batraciens de l'Indochine. Memoires de l'Institute Oceanographique de l'Indochine, Hanoi, Vietnam. 547 pp.
Brandon-Jones, D. 1996. The Asian Colobinae (Mammalia: Cercopithecidae) as indicators of Quaternary climatic change. *Biological Journal of the Linnean Society* 59:327–350.
Brandon-Jones, D., A.A. Eudey, T. Geissmann, C.P. Groves, D.J. Melnick, J.C. Morales, M. Shekelle, and C.-B. Stewart. 2004. Asian primate classification. *International Journal of Primatology* 25:97–164.
Clift, P., J.I. Lee, M.K. Clark, and J. Blusztajn. 2002. Erosional response of South China to arc rifting and monsoonal strengthening: A record from the South China Sea. *Marine Geology* 184:207–226.
Colinvaux, P.A., P.E. De Oliveira, and M.B. Bush. 2000. Amazonian and Neotropical plant communities on glacial time-scales: The failure of the aridity and refuge hypotheses. *Quaternary Science Reviews* 19:141–169.
Compton, J., and Le Hai Quang. 1998. *Borderline: An assessment of wildlife trade in Vietnam*. WWF Indochina Programme, Hanoi, Vietnam. 37 pp.
Conservation International. 2002. *Primates in Peril: The World's Top 25 Most Endangered Primates*. Conservation International, Washington, DC, USA. 20 pp.
Corbet, G.B., and J.E. Hill. 1992. *The Mammals of the Indomalayan Region: A Systematic Review*. Oxford University Press, Oxford, England, UK. 488 pp.
Dang N. Can, A.V. Abramov, A.N. Tikhonov, and A.O. Averianov. 2001. Annamite striped rabbit *Nesolagus timminsi* in Vietnam. *Acta Theriologica* 16:437–440.
Darevsky, I.S., and N.L. Orlov. 1992. A new subspecies of the dwarf snake *Calamaria lowi ingermarxi* ssp. nov. (Serpentes, Colubridae) from southern Vietnam. *Asiatic Herpetological Research* 1992:13–17.
DeKoninck, R. 1999. *Deforestation in Vietnam*. International Development Research Centre, Ottawa, Ontario, Canada. 100 pp.
de Laubenfels, D.J. 1975. *Mapping the World's Vegetation: Regionalization of Formations and Flora*. Syracuse University Press, Syracuse, New York, USA. 246 pp.
Delacour, J. 1930. On the birds collected during the fifth expedition to French Indo-China. *Ibis*, ser. 12, 6:564–599.
Delacour, J., P. Jabouille, and W.P. Lowe. 1928a. On the birds collected during the third expedition to French Indo-china. [Part I.] *Ibis*, ser. 12, 4:23–51.
Delacour, J., P. Jabouille, and W.P. Lowe. 1928b. On the birds collected during the third expedition to French Indo-China. [Part II.] *Ibis*, ser. 12, 4:285–317.
Donaldson, J.S. 2003. *Cycads. Status Survey and Conservation Action Plan*. IUCN, Gland, Switzerland and Cambridge, England, UK. 86 pp.
Dudgeon, D. 2000. Large-scale hydrological changes in tropical Asia: Prospects for riverine biodiversity. *BioScience* 50:793–806.
Eames, J.C., and C. Eames. 2001. A new species of Laughingthrush (Passeriformes: Garrulacinae) from the Central Highlands of Vietnam. *Bulletin of the British Ornithologists' Club* 121:10–23.
Eames, J.C., and P.G.P. Ericson. 1996. The Björkegren expeditions to French Indochina: A collection of birds from Vietnam and Cambodia. *Natural History Bulletin of the Siam Society* 44:75–111.
Eames, J.C., R. Eve, and A.W. Tordoff. 2001. The importance of Vu Quang Nature Reserve, Vietnam, for bird conservation, in the context of the Annamese lowlands Endemic Bird Area. *Bird Conservation International* 11:247–285.
Eames, J.C., Le Trong Trai, and Nguyen Cu. 1999a. A new species of Laughingthrush (Passeriformes: Garrulacinae) from the Western Highlands of Vietnam. *Bulletin of the British Ornithologists' Club* 119:4–15.
Eames, J.C., Le Trong Trai, Nguyen Cu, and R. Eve. 1999b. New species of Barwing Actinodura (Passeriformes: Sylviinae: Timaliini) from the Western Highlands of Vietnam. *Ibis* 141:1–10.
Fjeldså, J., and J.C. Lovett. 1997. Biodiversity and environmental stability. *Biodiversity and Conservation* 6:315–323.

FJELDSÅ, J., E. LAMBIN, AND B. MERTENS. 1999. Correlation between endemism and local ecoclimatic stability documented by comparing Andean bird distributions and remotely sensed land surface data. *Ecography* 22:63–78.

FLUX, J.E.C. 1990. The Sumatran rabbit *Nesolagus netscheri*. Pages 137–139 *in* J.A. Chapman and J.E.C. Flux, eds., *Rabbits, Hares and Pikas: Status Survey and Conservation Action Plan*. IUCN, Gland, Switzerland.

FONTAINE, H., AND D.R. WORKMAN. 1978. Review of the geology and mineral resources of Kampuchea, Laos and Vietnam. Pages 541–603 *in* P. Nutalaya, ed., *Proceedings of the Third Regional Conference on Geology and Mineral Resources of Southeast Asia, Bangkok, Thailand, November 14–18, 1978*. Asian Institute of Technology, Bangkok, Thailand.

GATHORNE-HARDY, F.J., SYAUKANI, R.G. DAVIES, P. EGGLETON, AND D.T. JONES. 2002. Quaternary rainforest refugia in south-east Asia: using termites (Isoptera) as indicators. *Biological Journal of the Linnean Society* 75:453–466.

GEISSMANN, T., NGUYEN XUAN DANG, N. LORMEE, AND F. MOMBERG. 2000. *Vietnam Primate Conservation Status Review 2000. Part 1: Gibbons*. Fauna and Flora International, Hanoi, Vietnam. 130 pp.

GROOMBRIDGE, B., AND M.D. JENKINS. 2002. *World Atlas of Biodiversity: Earth's Living Resources in the 21st Century*. University of California Press, Berkeley, California, USA. 340 pp.

GROVES, C.P., AND G.B. SCHALLER. 2000. The phylogeny and biogeography of the newly discovered Annamite artiodactyls. Pages 261–282 *in* E.S. Vrba and G.B. Schaller, eds., *Antelopes, Deer, and Relatives: Fossil Record, Behavioral Ecology, Systematics, and Conservation*.. Yale University Press, New Haven, Connecticut, USA.

GROVES, C.P., G.B. SCHALLER, G. AMATO, AND KHAMKHOUN KHOUNBOLINE. 1997. Rediscovery of the wild pig *Sus bucculentus*. *Nature* 386:335.

HAFFER, J. 1969. Speciation in Amazonian forest birds. *Science* 165:131–137.

HALL, R. 1998. The plate tectonics of Cenozoic SE Asia and the distribution of land and sea. Pages 99–131 *in* R. Hall and J.D. Holloway, eds., *Biogeography and Geological Evolution of SE Asia*. Backhuys, Leiden, The Netherlands.

HASSANIN, A., AND E.J.P. DOUZERY. 1999. Evolutionary affinities of the enigmatic saola (*Pseudoryx nghetinhensis*) in the context of the molecular phylogeny of Bovidae. *Proceedings of the Royal Society of London*, Series B: *Biological Sciences* 266:893–900.

HEANEY, L.R. 1991. A synopsis of climatic and vegetational change in Southeast Asia. *Climatic Change* 19:53–61.

HEWITT, G. 2000. The genetic legacy of the Quaternary ice ages. *Nature* 405:907–913.

HILL, M. 2000. Bird fauna of two protected forests in northern Vietnam. *Forktail* 16:5–14.

HURLEY, M.M. 2002. *Multi-taxon Biotic Inventories of Three Unprotected Forested Ecosystems in Vietnam*. Center for Biodiversity and Conservation at the American Museum of Natural History, New York, New York. <*http://research.amnh.org/biodiversity/vietnamresearch/*>.

HUTCHINSON, C.S. 1989. *Geological Evolution of South-east Asia*. Clarendon Press, Oxford, England, UK. 368 pp.

JABLONSKI, N.G. 1993. Quaternary environments and the evolution of primates in East Asia, with notes on two new specimens of fossil Cercopithecidae from China. *Folia Primatologica* 60:118–132.

KERSHAW, A.P., D. PENNY, S. VAN DER KAARS, G. ANSHARI, AND A. THAMOTHERAMPILLAI. 2001. Vegetation and climate in lowland southeast Asia at the Last Glacial Maximum. Pages 227–236 *in* I. Metcalfe, J.M.B. Smith, M. Morwood, and I. Davidson, eds., *Faunal and Floral Migrations and Evolution in SE Asia-Australasia*. A.A. Balkema, Lisse, Switzerland.

LECOINTRE, G., AND H. LE GUYADER. 2001. *Classification phylogénétique du vivant*. Belin, Paris, France. 543 pp.

LUNDE, D.P., G.G. MUSSER, AND NGUYEN TRUONG SON. 2003. A survey of small mammals from Mt. Tay Con Linh II, Vietnam, with the description of a new species of *Chodsigoa* (Insectivora: Soricidae). *Mammal Study* 28:31–46.

MACKINNON, J. 1997. *Protected Areas Systems Review of the Indo-Malayan Realm*. Asian Bureau for Conservation, Canterbury, England, UK. 198 pp.

Macey, J.R., J.A.I. Schulte, A. Larson, Z. Fang, Y. Wang, B.S. Tuniyev, and T.J. Papenfuss. 1998. Phylogenetic relationships of toads in the *Bufo bufo* species group from the Eastern escarpment of the Tibetan Plateau: A case of vicariance and dispersal. *Molecular Phylogenetics and Evolution* 9:80–87.

Metcalfe, I. 2001. Palaeozoic and Mesozoic tectonic evolution and biogeography of SE Asia-Australasia. Pages 15–34 *in* I. Metcalfe, J.M.B. Smith, M. Morwood, and I. Davidson, eds., *Faunal and Floral Migrations and Evolution in SE Asia-Australasia*. A.A. Balkema, Lisse, Switzerland.

Morley, R.J. 2000. *Origin and Evolution of Tropical Rain Forests*. John Wiley & Sons, Chichester, UK. 362 pp.

Nadler, T. 1997. A new subspecies of douc langur, *Pygathrix nemaeus cinereus* ssp. nov. *Der Zoologische Garten* 67:165–176.

Nguyen Nghia Thin, and D.K. Harder. 1996. Diversity of the flora of Fan Si Pan, the highest mountain in Vietnam. *Annals of the Missouri Botanical Garden* 83:404–408.

Nguyen Tien Hiep, and Phan Ke Loc. 1999. The cycads of Vietnam. Pages 24–32 *in* C.J. Chen, ed., *Biology and Conservation of Cycads: Proceedings of the Fourth International Conference on Cycad Biology, Panzhihua, Sichuan, China, 1–5 May 1996*. International Academic Publishers, Beijing, China.

Nguyen Xuan Dang, Pham Trong Anh, and Le Hing Tuyen. 2000. *Results of Otter Survey in U Minh Thuong Nature Reserve, Kien Giang Province, Vietnam from 1 to 30 March, 2000*. Care International in Vietnam, Hanoi, Vietnam. 42 pp.

Oliver, W.L.R. 1993. *Pigs, Peccaries, and Hippos. Status Survey and Conservation Action Plan*. IUCN, Gland, Switzerland. 202 pp.

Orlov, N.L., A. Lathrop, R.W. Murphy, and Ho Thu Cuc. 2001. Frogs of the family Rhacophoridae (Anura: Amphibia) in the Northern Hoang Lien Mountains (Mount Fan Si Pan, Sa Pa District, Lao Cai Province), Vietnam. *Russian Journal of Herpetology* 8:17–44.

Osgood, W.H. 1932. Mammals of the Kelley-Roosevelt's and Delacour Asiatic Expeditions. *Field Museum of Natural History, Zoological Series* 18:193–339.

Pham Binh Quyen, and Truong Quang Hoc. 2000. Vietnam: North and central highlands. Pages 337–370 *in* A. Wood, P. Stedman-Edwards, and J. Mang, eds., *The Root Causes of Biodiversity Loss*. Earthscan, London, England, UK.

Pham Mong Giao, Do Tuoc, Vu Van Dung, E.D. Wikramanayake, G. Amato, P. Arctander, and J.R. MacKinnon. 1998. Description of *Muntiacus truongsonensis*, a new species of muntjac (Artiodactyla: Muntiacidae) from Central Vietnam, and implications for conservation. *Animal Conservation* 1:61–68.

Pine, R.H. 1994. New mammals not so seldom. *Nature* 368:593.

Poffenberger, M., and Nguyen Huy Phon. 1998. The National Forest Sector. Pages 1–17 *in* M. Poffenberger, ed., *Stewards of Vietnam's Upland Forests*. Asia Forest Network, Tagbilaran, Phillipines.

Rabinowitz, A. 1997. Lost world of the Annamites. *Natural History* 106:14–18.

Robson, C. 2000. *A Guide to the Birds of Southeast Asia: Thailand, Peninsular Malaysia, Singapore, Myanmar, Laos, Vietnam, Cambodia*. Princeton University Press, Princeton, New Jersey, USA. 504 pp.

Rundel, P.W. 2000. *Forest Habitats and Flora in Lao PDR, Cambodia, and Vietnam: Desk Study for the Ecoregion-based Conservation in the Forests of the Lower Mekong Biological Assessment Workshop*. WWF Indochina Programme, Phnom Penh, Cambodia. 197 pp.

Schaller, G.B., and E.S. Vrba. 1996. Description of the giant muntjac (*Megamuntiacus vuquangensis*) in Laos. *Journal of Mammalogy* 77:675–683.

Stattersfield, A.J., M.J. Crosby, A.J. Long, and D.C. Wege. 1998. *Endemic Bird Areas of the World: Priorities for Biodiversity Conservation*. BirdLife International, Cambridge, England, UK. 846 pp.

Stein, N. 2002. Crisis in a coffee cup. *Fortune* 146:204–218.

Surridge, A.K., R.J. Timmins, G.M. Hewitt, and D.J. Bell. 1999. Striped rabbits in Southeast Asia. *Nature* 400:726.

Sweet, P.R., and C.J. Vogel. (In prep.) A new babbler (Passeriformes: Sylviinae) from Vietnam.

Sweet, P.R., S. Reddy and C.J. Vogel. (In prep.) Species limits in *Jabouilleia*: A revision of the genus with implications for the species concept in avian conservation.

Timmins, R.J., and Trinh Viet Cuong. 2001. *An Assessment of the Conservation Importance of the Huong Son (Annamite) Forest, Ha Tinh Province, Vietnam, Based on the Results of a Field Study for Large*

Mammals and Birds. Center for Biodiversity and Conservation at the American Museum of Natural History, New York, New York, USA. 94 pp.

TORDOFF, A.W., TRAN HIEU MINH, AND TRAN QUANG NGOC. 2000. *A Feasibility Study for the Establishment of Ngoc Linh Nature Reserve, Quang Nam Province, Vietnam*. Birdlife International Vietnam Programme, Hanoi, Vietnam. 74 pp.

UDVARDY, M.D.F. 1975. *A Classification of the Biogeographical Provinces of the World*. IUCN, Morges, Switzerland. 48 pp.

VIDAL, J.E. 1960. *La Végétation du Laos*. Souladoure, Toulouse, France. 4 vols.

VO QUY, AND LE THAC CAN. 1994. Conservation of forest resources and the greater biodiversity of Vietnam. *Asian Journal of Environmental Management* 2:55–59.

VO TRI CHUNG, E. CRYSTAL, M. POFFENBERGER, NGUYEN HUY DZUNG, VU VAN DZUNG, NGUYEN HUY PHON, AND P. WALPOLE. 1998. The National Forest Sector. Pages 39–69 *in* M. Poffenberger, ed., *Stewards of Vietnam's Upland Forests*. Asia Forest Network, Tagbilaran, Phillipines.

VOGEL, C.J., P.R. SWEET, L.M. HUNG., AND M.M. HURLEY. 2003. Ornithological records from Ha Giang province, north-east Vietnam, during March-June 2003. *Forktail* 19:21–30.

VORIS, H.K. 2000. Maps of Pleistocene sea levels in Southeast Asia: shorelines, river systems and time durations. *Journal of Biogeography* 27:1153–1167.

VU VAN DUNG, PHAM MONG GIAO, NGUYEN NGOC CHINH, DO TUOC, P. ARCTANDER, AND J. MACKINNON. 1993. A new species of living bovid from Vietnam. *Nature* 363:443–445.

WEGE, D.C., A.J. LONG, MAI KY VINH, VU VAN DUNG, AND J.C. EAMES. 1999. *Expanding the Protected Areas Network in Vietnam for the 21st Century: An Analysis of the Current System with Recommendations for Equitable Expansion*. BirdLife International Vietnam Programme, Hanoi, Vietnam.

WERNER, J., AND D. BÉLANGER. 2002. *Gender, Household, State: Doi Moi in Vietnam*. Southeast Asia Program Publications, Cornell University, Ithaca, New York, USA. 151 pp.

ZHOU, W., D.J. DONAHUE, S.C. PORTER, T.A. JULL, X. LI, M. STUIVER, Z. AN, E. MATSUMOTO, AND G. DONG. 1996. Variability of monsoon climate in East Asia at the end of the last glaciation. *Quaternary Research* 46:219–229.

ZOOLOGICAL RECORD. 2002. Zoological Record 1978–2002. Retrieved December 2002. Biosis, Philadelphia, Pennsylvania. URL: <*http://www.biosis.org*>